

COLOR SENSOR CIRCUIT WITH INTEGRATED PROGRAMMABLE GAIN SELECTION

BACKGROUND

[0001] The present invention relates to detection of light and pertains particularly to a color sensor circuit with integrated programmable gain selection.

[0002] A typical color sensor circuit detects three colors. The three colors are typically red, blue and green. Three separate components are used to implement each color of a color sensor. A first component includes a photodiode and filter that are used to detect an illuminance for the color. The second component is an operational amplifier that functions as a transimpedance amplifier. The third component is a feedback resistor. Typically, the three components for each color are mounted on a printed circuit board (PCB).

[0003] Typically, the photodiodes have a relatively large area which is necessary to generate high photocurrents. The high photocurrents are necessary to make the sensor circuit less susceptible to noise. Correspondingly large values for feedback resistors are also used. The values of external resistors are selected to give the proper gain needed for the transimpedance amplifier.

[0004] The required feedback resistance and feedback capacitance vary from system to system, which has made it necessary in the prior art to implement the feedback resistor on a separate component from the photodiodes.

SUMMARY OF THE INVENTION

[0005] In accordance with embodiments of the present invention, a color sensor is implemented on a single integrated circuit chip. The color sensor includes a plurality of color sensor circuits and a gain selection control. Each color sensor circuit in the plurality of color sensor circuits includes a light detector, an amplifier and a gain selection circuit. The amplifier is connected to the light detector. The amplifier amplifies a signal from the light detector. The gain selection circuit is connected to the amplifier. The gain selection controls gain of the amplifier. The gain selection circuit includes a variable feedback resistance. The gain selection control selects a separate value of the variable feedback resistance for each color sensor circuit.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] Figure 1 is a simplified block diagram of a color sensor circuit in accordance with an embodiment of the present invention.

[0007] Figure 2 is a simplified block diagram of a gain selection circuit in accordance with an embodiment of the present invention.

[0008] Figure 3 is a graph that shows output swing verse illuminance in accordance with an embodiment of the present invention.

[0009] Figure 4 is a simplified block diagram of a color sensor circuit in accordance with another embodiment of the present invention.

[0010] Figure 5 is a simplified block diagram of a color sensor circuit in accordance with another embodiment of the present invention.

DESCRIPTION OF THE EMBODIMENT

[0011] Figure 1 shows a color sensor circuit implemented on a single integrated circuit (IC) chip 10. A first color circuit generates a first output voltage placed on an output 18. The first output voltage indicates detected illuminance of a first color. For example, the first color is red. A photo diode and filter 14 detect illuminance of the first color. Photo diode and filter 14 is connected between a ground signal 11 and a line 19. An operational amplifier 13 amplifies voltage on line 19 to produce the first output voltage placed on output 18. Gain is controlled by a gain selection circuit 15. Gain selection circuit 15 includes a feedback resistance 17 and a compensation capacitance 16. Operational amplifier 13 is connected to ground signal 11 and a V_{CC} signal 12, as shown.

[0012] A second color circuit generates a second output voltage placed on an output 28. The second output voltage indicates detected illuminance of a second color. For example, the second color is green. A photo diode and filter 24 detect illuminance of the second color. Photo diode and filter 24 is connected between ground signal 11 and a line 29. An operational amplifier 23 amplifies voltage on line 29 to produce the second output voltage placed on output 28. Gain is controlled by a gain selection circuit 25. Gain selection circuit 25 includes a feedback resistance 27 and a compensation capacitance 26. Operational amplifier 23 is connected to ground signal 11 and V_{CC} signal 12, as shown.

[0013] A third color circuit generates a third output voltage placed on an output 38. The third output voltage indicates detected illuminance of a third color. For example, the third color is blue. A photo diode and filter 34 detect illuminance of the third color. Photo diode and filter 34 is connected between ground signal 11 and a line 39. An operational amplifier 33 amplifies voltage on line 39 to produce the third output voltage placed on output 38. Gain is controlled by a gain selection circuit 35. Gain selection circuit 35 includes a feedback resistance 37 and a compensation capacitance 36. Operational amplifier 33 is connected to ground signal 11 and V_{CC} signal 12, as shown.

[0014] A gain selection control circuit 39 controls selected values for feedback resistance 17, compensation capacitance 16, feedback resistance 27, compensation capacitance 26, feedback resistance 37 and compensation capacitance 36. For example, gain selection for each color is selected independent of gain selection for the other colors. This allows individual selection of resistance to achieve an optimum voltage swing for the output voltage for each color. Resolution (accuracy) of the output voltage for each color is based on the number of bits used for gain selection. The more bits used, the greater resolution that can be achieved.

[0015] Figure 2 is an example implementation of gain selection circuit 15. Feedback resistance 17 (shown in Figure 1) is implemented by a resistor 51, a resistor 52, a resistor 53, a resistor 54, a switch 55, a switch 56, a switch 57 and a switch 58 connected as shown. Compensation capacitance 16 (shown in Figure 1)

is implemented by a capacitor 61, a capacitor 62, a capacitor 63, a capacitor 64, a switch 66, a switch 67 and a switch 68 connected as shown.

[0016] For the example implementation of gain selection circuit 15, gain can be controlled by two bits. The two bits allow for selection of four different values for feedback resistance 17 and four different values for compensation capacitance 16. Different values for feedback resistance 17 are selected using switches (SW) 55 through 58. For example, the four different values for resistance are labeled R_0 (resistor 51 + resistor 52 + resistor 53 + resistor 54), R_1 (resistor 52 + resistor 53 + resistor 54), R_2 (resistor 53 + resistor 54), R_3 (resistor 54),

[0017] Different values for compensation capacitance 16 are selected using switches (SW) 66 through 68. The compensation capacitance is utilized in order to maintain stability of the system. When the gain (controlled by the feedback resistance) is changed, this results in a change of frequency response that affects the stability of the system. For each gain select option, the corresponding compensation capacitance shifts the systems poles' positions, thus maintaining sufficient gain and phase margin for stable response. Values of capacitor 61, capacitor 62, capacitor 63 and capacitor 64 are selected so that system stability is maintained.

[0018] Table 1 below gives position of the switches for each of the possible selection bit combinations (00,01,10,11)

Table 1

Bit Select		SW 55	SW 56	SW 57	SW 58	SW 66	SW 67	SW 68
00	R ₀	On	Off	Off	Off	On	On	On
01	R ₁	Off	On	Off	Off	On	On	Off
10	R ₂	Off	Off	On	Off	On	Off	Off
11	R ₃	Off	Off	Off	On	Off	Off	Off

[0019] Values selected for resistors 51 through 54 are based on the circuit characteristics and the desired accuracy (α) of the sensing system. For example, an accuracy of 60% (i.e., $\alpha = 60\%$) means that any selected range from 0 to a selected maximum illuminance is guaranteed to utilize at least 60% of the full voltage range (i.e., 0 volts to V_{CC}) provided the selected maximum is within a defined range. Likewise, an accuracy of 80% (i.e., $\alpha = 80\%$) means that any selected range from 0 to a selected maximum illuminance is guaranteed to utilize at least 80% of the full voltage range provided the selected maximum is within the defined range.

[0020] For example, for the case where maximum selected resistance (R₀) of 100 mega ohms (M Ω) results in a maximum illuminance of 100.0 lux, Table 2 below sets out the required resistance (R₀,R₁,R₂,R₃) and resulting illuminance (M₀,M₁,M₂,M₃) for the case where accuracy (α) equals 60%.

Table 2

Bit Select		Resistance		Maximum Illuminance
00	R ₀	100	M ₀	100
01	R ₁	60	M ₁	167
10	R ₂	36	M ₂	278
11	R ₃	21.6	M ₃	463

[0021] As can be deduced from Table 2, the following relationship holds:

$$R_{n+1} = \alpha R_n$$

$$M_{n+1} = R_n / \alpha$$

[0022] For example, for the case where maximum selected resistance (R_0) of 100 mega ohms ($M\Omega$) results in a maximum illuminance of 100.0 lux, Table 3 below sets out the required resistance (R_0, R_1, R_2, R_3) and resulting illuminance (M_0, M_1, M_2, M_3) for the case where accuracy (α) equals 80%.

Table 3

Bit Select		Resistance		Maximum Illuminance
00	R_0	100	M_0	100
01	R_1	80	M_1	125
10	R_2	64	M_2	156
11	R_3	51.2	M_3	195

[0023] As can be seen from Table 3, the following relationship still holds:

$$R_{n+1} = \alpha R_n$$

$$M_{n+1} = R_n / \alpha$$

[0024] As can be seen from Table 3, for higher accuracy (increased α), the illuminance range reduces and the resistance values are higher. In order to maintain the same illuminance range with increasing accuracy (α), it is necessary to add selection bits.

[0025] Figure 3 is a graph that shows output swing verses illuminance for the case where maximum selected resistance (R_0) of 100 mega ohms ($M\Omega$) results in a maximum illuminance of 100.0 lux, and accuracy (α) equals 60%.

[0026] An axis 71 represents illuminance (lux) detected by photo diode and filter 14 (shown in Figure 1). An axis 72 represents the first output voltage placed on output 18 (shown in Figure 1).

[0027] Trace 73 represents the response when selection switches 55 through 58 (shown in Figure 2) select R_0 (resistor 51 + resistor 52 + resistor 53 + resistor 54). Trace 74 represents the response when selection switches 55 through 58 (shown in Figure 2) select R_1 (resistor 52 + resistor 53 + resistor 54). Trace 75 represents the response when selection switches 55 through 58 (shown in Figure 2) select R_2 (resistor 53 + resistor 54). Trace 76 represents the response when selection switches 55 through 58 (shown in Figure 2) select R_3 (resistor 54).

[0028] As can be seen from Figure 3, for a selected maximum illuminance within the defined range of 60 lux to 463 lux, any selected range from 0 to the selected maximum illuminance is guaranteed to utilize at least 60% of the full voltage range. All that is necessary is to utilize the selection bits to select the correct resistance value.

[0029] For example, suppose the selected maximum illuminance is 120 lux. For this case, the selected resistance would be R_1 and the resulting response is represented by trace 74. As can be seen from a labeled point 77 on the graph shown in Figure 3, the selected range from 0 to a 215 lux utilizes 71.9 % of the full voltage range.

[0030] In accordance with various embodiments, the number of channels can vary based on the application. For example, Figure 4 shows a color sensor circuit implemented on a single integrated circuit (IC) chip 110. A first color

circuit generates a first output voltage placed on an output 118. The first output voltage indicates detected illuminance of a first color. For example, the first color is red. A photo diode and filter 114 detect illuminance of the first color. Photo diode and filter 114 is connected between a ground signal 111 and a line 119. An operational amplifier 113 amplifies voltage on line 119 to produce the first output voltage placed on output 118. Gain is controlled by a gain selection circuit 115. Operational amplifier 113 is connected to ground signal 111 and a V_{CC} signal 112, as shown.

[0031] A second color circuit generates a second output voltage placed on an output 128. The second output voltage indicates detected illuminance of a second color. For example, the second color is green. A photo diode and filter 124 detect illuminance of the second color. Photo diode and filter 124 is connected between ground signal 111 and a line 129. An operational amplifier 123 amplifies voltage on line 129 to produce the second output voltage placed on output 128. Gain is controlled by a gain selection circuit 125. Operational amplifier 123 is connected to ground signal 111 and V_{CC} signal 112, as shown.

[0032] A third color circuit generates a third output voltage placed on an output 138. The third output voltage indicates detected illuminance of a third color. For example, the third color is blue. A photo diode and filter 134 detect illuminance of the third color. Photo diode and filter 134 is connected between ground signal 111 and a line 139. An operational amplifier 133 amplifies voltage on line 139 to produce the third output voltage placed on output 138.

Gain is controlled by a gain selection circuit 135. Operational amplifier 133 is connected to ground signal 111 and V_{CC} signal 112, as shown.

[0033] A fourth color circuit generates a fourth output voltage placed on an output 148. The fourth output voltage indicates detected illuminance of a fourth color. For example, the third color is white. A photo diode and filter 144 detect illuminance of the third fourth. Photo diode and filter 144 is connected between ground signal 111 and a line 149. An operational amplifier 143 amplifies voltage on line 149 to produce the fourth output voltage placed on output 148. Gain is controlled by a gain selection circuit 145. Operational amplifier 143 is connected to ground signal 111 and V_{CC} signal 112, as shown.

[0034] For example, for a six channel system, six color circuits are included that detect illuminance for six colors. For example, the six colors are red, blue, green, cyan, magenta and yellow. Alternatively, other colors can be used.

[0035] While Figure 1 and Figure 4 show embodiments with single stage amplifiers, as will be understood by persons of ordinary skill in the art, multiple stage amplifiers can also be used. Gain selection can be controlled for one or multiple stages of the amplifiers, depending upon the application.

[0036] For example, Figure 5 shows a multiple stage amplifier with gain selection for each stage. Specifically, a color circuit generates a circuit output voltage placed on a circuit output 238. A photo diode and filter 214 detect illuminance of the first color. Photo diode and filter 214 is connected between a ground signal 211 and a line 219. An operational amplifier 213 amplifies voltage on line 219 to produce an intermediate output voltage placed on output

218. Gain is controlled by a gain selection circuit 215. Operational amplifier 213 is connected to ground signal 211 and a V_{CC} signal 212, as shown.

[0037] An operational amplifier 223 amplifies voltage on line 218 to produce an intermediate voltage placed on output 228. Gain is controlled by a gain selection circuit 225. Operational amplifier 223 is connected to ground signal 211 and a V_{CC} signal 212, as shown. An operational amplifier 233 amplifies voltage on line 228 to produce the circuit output voltage placed on a circuit output 238. Gain is controlled by a gain selection circuit 235. Operational amplifier 233 is connected to ground signal 211 and a V_{CC} signal 212, as shown.

[0038] The foregoing discussion discloses and describes merely exemplary methods and embodiments of the present invention. As will be understood by those familiar with the art, the invention may be embodied in other specific forms without departing from the spirit or essential characteristics thereof. Accordingly, the disclosure of the present invention is intended to be illustrative, but not limiting, of the scope of the invention, which is set forth in the following claims.